Application of Internet of Things to reduce Occupational Heat Strain for outdoor workers in Fighting Climate Change (Narrative Review)

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Abstract:

BACKGROUND : The risk of heat stress in work situations has increased due to the increasing effects of climate change, hence creative solutions are needed to protect workers' health and safety. The potential of Internet of Things (IoT) technology to lessen outdoor workers' occupational heat strain is examined in this article.

METHODS: A thorough literature review process was applied to screen 224 studies in total. Out of them, 36 research met strict criteria for quality and relevance, providing a good foundation for the analysis.

RESULTS: Even while IoT has many benefits, like better worker safety and environmental control, there are a number of obstacles that prevent it from being used effectively. Key challenges include issues with power management, user acceptability, privacy and security concerns, integration, and data accuracy and reliability. Significant obstacles are also presented by the expenses of implementing IoT systems and maintaining regulatory compliance.

CONCLUSION: By proactively implementing and consistently enhancing Internet of Things solutions, companies may efficiently reduce thermal stress and safeguard the welfare of their employees.

Keywords: Outdoor workers, real-time monitoring , IoT technology , thermal comfort.

Introduction

In fact, climate change is making occupational heat stress a serious problem that is especially bad for outdoor workers in industries like manufacturing, construction, and agriculture. Significant evidence for this problem is provided by recent research conducted between 2017 and 2024:

Heat stress is the primary cause of weather-related mortality, according to the World Health Organization (WHO), and it can make pre-existing conditions like diabetes, asthma, and cardiovascular disease worse. Climate change is causing an exponential increase in the number of individuals exposed to intense heat in every region of the world. Between 2000 and 2004 and 2017 and 2021, the number of deaths attributed to heat for those over 65 years of age increased by almost 85%. (۱). A study published by the International Labour Organization (ILO) estimates that at least 2.41 billion workers experience high temperatures at work each year. These temperatures can have a number of negative health effects, such as heat exhaustion, heat stress, rhabdomyolysis, and cardiovascular disease. The study also reports that there are 22.85 million occupational injuries, 18,970 work-related deaths, and 2.09 million disability-adjusted life years (DALYs) that can be attributed to high temperatures each year(۲) .

Prolonged exposure to high temperatures and humidity puts outdoor workers at risk for heat-related illnesses. A systematic review published in 2021 found a positive correlation between climate change and occupational heat strain in outdoor workers, with particular emphasis on those in manufacturing, construction, and agriculture(۳) .

Since 2017, the use of the Internet of Things (IoT) to mitigate occupational heat stress has gained momentum, offering creative approaches for adaptive interventions and real-time monitoring. IoT technology has emerged as a promising tool to address these issues. IoT systems enable continuous monitoring of physiological responses (e.g., body temperature, heart rate) and environmental conditions (e.g., temperature, humidity) using wearable sensors. This data is critical for assessing heat stress in real-time and putting timely interventions into action (e.g., modifying work schedules, offering hydration, or turning on cooling systems (4). This claim is supported by a number of credible sources from 2017 to 2024, which state that cutting-edge Internet of Things (IoT) technologies have in fact demonstrated considerable promise in improving workplace safety and productivity by reducing occupational heat stress:

In order to improve worker safety in manufacturing environments, an integration of IoT and machine learning technologies is highlighted in a 2024 study published in the International Journal for Multidisciplinary Research (IJFMR). The study highlights the application of wearable technology with sensors to track environmental variables including temperature, humidity, and air quality as well as the physiological states of employees. By identifying possible safety problems, these IoT solutions enable preemptive steps to reduce risks and avoid accidents(۵) .

IoT devices are enhancing workplace safety, especially in challenging work environments like factories, energy production facilities, and construction sites, according to a 2019 Perle Systems article. According to the report, wearable Internet of things (IoT) sensors can identify "out-of-tolerance conditions for heat, humidity, and noise levels," warning employees of potentially dangerous changes in their environment(۶) .

These sources show that IoT technologies are being actively used to address workplace safety issues, including occupational heat stress. In this review, we investigate how IoT can be used to reduce occupational heat strain in outdoor workers, including how it can be used to monitor physiological and environmental conditions, enable early warning systems, and provide data-driven recommendations to improve worker safety and productivity. Additionally, we look at the wider implications of IoT in mitigating climate change by encouraging sustainable work practices and lowering the environmental impact of outdoor labor activities.

Methods:

The suitability of IoT technology for outdoor work was verified by a comprehensive assessment of the scientific literature. Since about 2017, the use of the Internet of Things (IoT) to lessen heat stress at work has been investigated (٤) , The following specific keywords, "Internet of Things," "climatic changes," "outdoor workers," and "Occupational heat strain," were used in the search title; focus, substance, and constraints were initially determined in accordance with the review's objective; afterwards, the search and review process' inclusion and exclusion criteria were established. All studies published from 2017 to 2024 that discussed IoT technology techniques in occupational health were included in the search. Data were obtained from a range of online scientific sources accessed using databases such as Google Scholar, ISI Web of Science, Scopus, and Science Direct:

a) Only research in the area of occupational health is included in the following studies, b) scientific publications published in international journals with (academic) peer review, c) papers published in English and Persian, and finally, by eliminating In a similar vein, resource management tools (software like EndNote) were used to review ٣٦ articles. The process of searching and selecting articles is shown in Figure1.

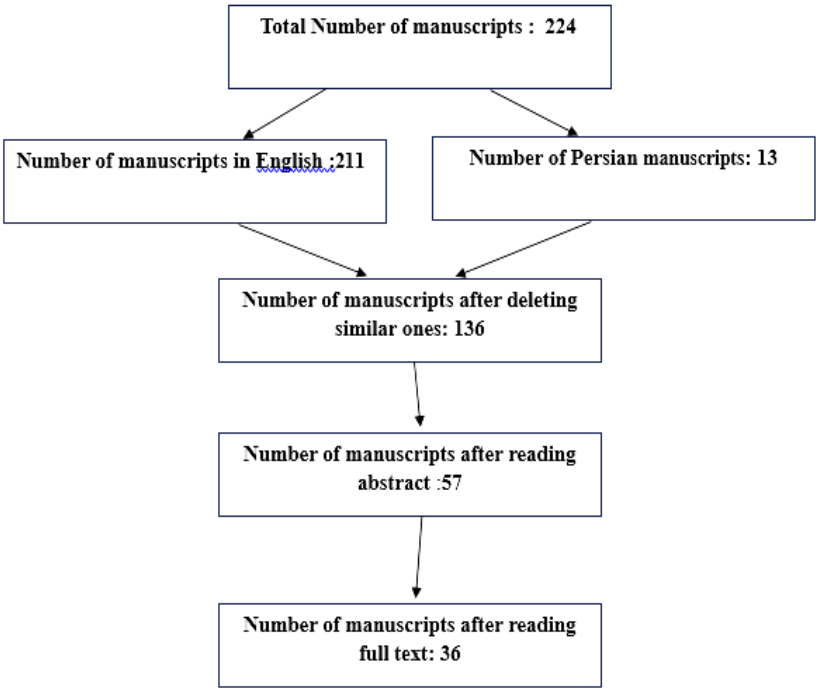

Fig1. The process of searching and selecting articles

Results and Discussion:

۱ .The concept of Internet of Things

The term "Internet of Things" (IoT) describes a network of physically connected objects, including cars, appliances, and other household equipment, that are network-connected and integrated with sensors, software, electronics, and network connectivity. This allows the objects to trade and collect data(۶) . By 2025, there will be about 50 billion smart devices worldwide, including phones, cameras, smartwatches, TVs, cars, smart AR/VR devices, healthcare devices, smart watches, smart homes, smart cities, smart healthcare systems, smart grids and metering systems, and much more. The Internet of Things has quickly taken hold of many domains, including healthcare, smart cars, agriculture, smart homes, smart cities, smart industrial processes and operations, traffic management systems, and much more(۷) . Some of the essential application areas of the Internet of Things are depicted in Fig .۲

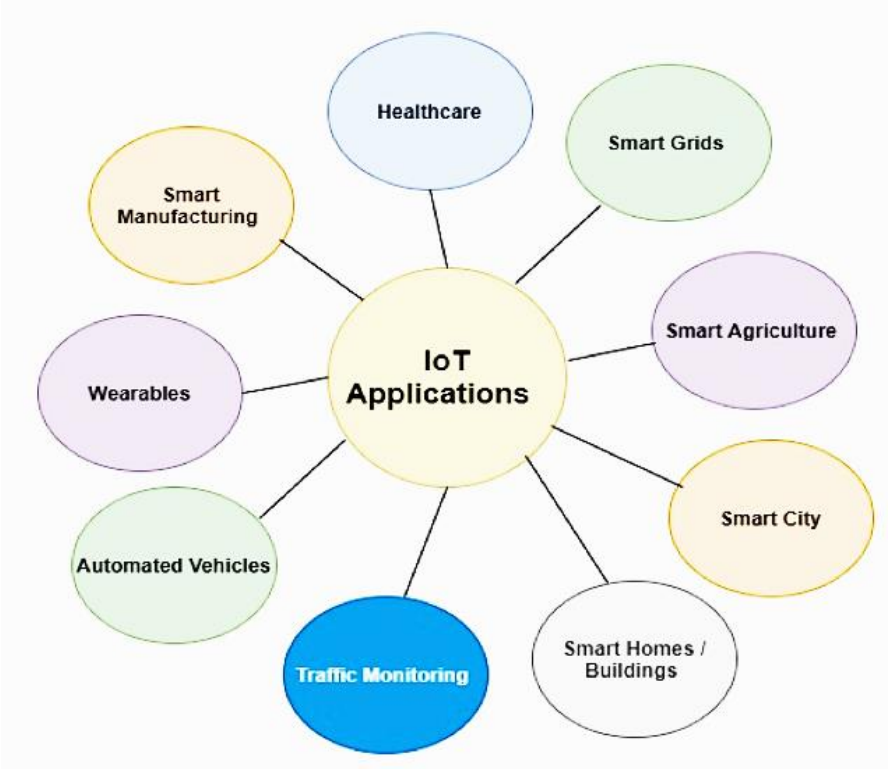

Fig2. Essential application area of IoT(8)

IoT technologies have demonstrated a great deal of promise for improving workplace safety and reducing hazards like heat stress in the context of occupational health.IoT is a paradigm that has changed old ways of living and working into a high-tech lifestyle, claims a 2019 study in the Journal of Big Data (6). The integration of IoT technology in occupational health practices leads to:

Safer Work Environments: Ensuring safe working conditions is facilitated by ongoing monitoring and real-time alerts.

Prevention of Injuries and Illnesses: Injuries and diseases are avoided by early identification of risk factors and medical problems.

Regulatory Compliance: Precise data gathering guarantees adherence to health and safety guidelines.

Enhanced Worker Well-being: Keeping an eye on environmental factors and physiological indicators promotes overall worker well-being (9). These IoT-based occupational health applications show how to approach workplace safety pro-actively by emphasizing real-time monitoring and prevention above reactive actions. In order to provide safer and better work environments, the application of IoT in occupational health is a key advancement (10).

2. Key technologies of the Internet of Things in reducing occupational heat Strain

Research on the use of Internet of Things (IoT) technology to lessen occupational heat strain is crucial, especially in light of the rise in the frequency of extreme heat events:

a. Wearable Devices

Real-time physiological parameter monitoring of workers is mostly dependent on wearable technology. These gadgets, which include smart clothes and bands, have sensors that measure body temperature, sweat production, and heart rate. Wearable smart bands, for example, are used by an Internet of Things-based platform for monitoring the physiological data of construction workers to continuously monitor these parameters and provide early warning signs of heat strain (11).

b. Environmental Sensors

Environmental sensors keep an eye on things like humidity, temperature, and radiant heat. In order to enable prompt responses to reduce heat stress, these sensors can be installed in workplaces to offer real-time data on ambient conditions. In order to identify thermal comfort in industrial settings and identify heat stress in real time, an Internet of Things (IoT)-aware smart system has been developed that continuously monitors skin temperature and heart rate (12).

c. Noninvasive Dual-Heat-Flux Thermometers

Noninvasive dual-heat-flux thermometers are incorporated into advanced IoT devices to precisely monitor deep body temperature. This technique is essential for preventing heatstroke since it gives an accurate and non-intrusive measurement of the core body temperature. This kind of thermometer is used, for instance, in an advanced Internet of Things system designed to prevent heatstroke by monitoring and managing heat strain. The sensor gathers physiological and environmental data to determine the danger of heatstroke, and the user is advised to assess their physical condition to avoid thermal harm (13).

d. Machine Learning Algorithms

Algorithms for machine learning (ML) are important for assessing the information gathered from Internet of Things devices. The prediction of heat-related disorders is made possible by these algorithms, which are able to recognize patterns and correlations between physiological responses and environmental variables. For example, a study on the prediction of heat stroke combines machine learning algorithms with Internet of Things devices to identify and forecast heat-related ailments, offering early alerts and preventive actions (14).

e. Predictive Models

In exceptionally hot conditions, predictive models created with IoT and ML technologies predict personal heat strain. These models provide streamlined forecasts using interpretable machine learning techniques, assisting companies and employees in taking preventative action to lessen heat strain(15).

By offering accurate measurements, ongoing monitoring, and predictive insights, these Internet of Things (IoT) technologies help to reduce occupational heat strain and improve worker safety and health in hot situations.

You can see a summary of the research efforts dedicated to the development of Internet of Things technologies in the field of reducing the occupational heat Strain in Table ۱.

Table 1

Summary of the research efforts dedicated to the development of Internet of Things technologies in the field of reducing the occupational heat Strain

Author and year	Title	Type of technology used	Reference
Pham, Sean et al(2020)	Wearable Sensor System to Monitor Physical Activity and the Physiological Effects of Heat Exposure	Wearable Devices	(16)
Runkle, Jennifer D .et al (2019)	Evaluation of wearable sensors for physiologic monitoring of individually experienced temperatures in outdoor workers in southeastern U.S.	Wearable Devices	(17)
Sean R. Notley et al (2018)	On the use of wearable physiological monitors to assess heat strain during occupational heat stress	Wearable Devices	(18)
Hwang, Sungjoo et al (2017)	Wristband-type wearable health devices to measure construction workers' physical demands	Wearable Devices	(19)
Lee, Wonil et al (2017)	Wearable sensors for monitoring on-duty and off-duty worker physiological status and activities in construction	Wearable Devices	(20)
Pancardo, Pablo et al (2015)	Real-Time Personalized Monitoring to Estimate Occupational Heat Stress in Ambient Assisted Working	Environmental Sensors	(21)
Morabito, Marco et al (2019)	An Occupational Heat–Health Warning System for Europe: The HEAT-SHIELD Platform	Environmental Sensors	(22)
Sergi, Ilaria et al (2021)	An IoT-aware smart system to detect thermal comfort in industrial environments. 2021 6th International Conference on Smart and Sustainable Technologies	Environmental Sensors	(12)
Żmigrodzki, Jakub et al(202400	Analytical Analysis of Factors Affecting the Accuracy of a Dual-Heat Flux Core Body Temperature Sensor	Noninvasive Dual-Heat-Flux Thermometers	(23)

Tamura, Toshiyo et al (2022)	An Advanced Internet of Things System for Heatstroke Prevention with a Noninvasive Dual-Heat-Flux Thermometer	Noninvasive Dual-Heat-Flux Thermometers	(13)
Lu, Hanzi et al (2023)	Development of a Core Body Thermometer Applicable for High-Temperature Environment Based on the Zero-Heat-Flux Method	Noninvasive Dual-Heat-Flux Thermometers	(24)
Choi, Yujin et al(2024)	A machine learning-based forecasting model for personal maximum allowable exposure time under extremely hot environments	Machine Learning Algorithms	(25)
Seo, Seungwon et al (2023)	An interpretable machine learning approach for forecasting personal heat strain considering the cumulative effect of heat exposure	Machine Learning Algorithms	(26)
Yin, Lim et al (2024)	Heat stroke prediction: a perspective from the internet of things and machine learning approach	Machine Learning Algorithms	(14)
Shakerian, Shahrad et al (2021)	Assessing occupational risk of heat stress at construction: A worker-centric wearable sensor-based approach	Predictive Models	(27)
Du, Chenqiu et al (2019)	Modification of the Predicted Heat Strain (PHS) model in predicting human thermal responses for Chinese workers in hot environments	Predictive Models	(28)
Morabito, Marco et al (2019)	An Occupational Heat–Health Warning System for Europe: The HEAT-SHIELD Platform	Predictive Models	(22)

3. The benefits of using the IOT to reduce thermal stress caused by climate change

In particular, IoT devices like wearable sensors and environmental monitors provide real-time data on workers' physiological states and environmental conditions, which enables timely interventions to prevent heat-related illnesses. The Internet of Things (IoT) offers many benefits in reducing thermal stress caused by climate change, especially in occupational settings (12). IoT systems are able to forecast possible heat stress events by utilizing machine learning algorithms and data analytics, taking into account past performance as well as present environmental factors. Because of its predictive power, preemptive actions can be taken, such modifying work schedules or putting cooling techniques in place before heat stress happens(29). Indoor surroundings can be optimized by IoT-enabled smart technologies to preserve thermal comfort. Based on real-time data, these systems regulate HVAC, regulate ventilation, and control shade devices to keep indoor conditions within safe and acceptable bounds. It is possible to examine the data gathered from IoT devices to spot trends and guide decision-making procedures. Organizations can create efficient heat mitigation methods by restructuring workspaces, introducing cooling equipment, or altering work-rest cycles with the use of this data-driven strategy. The extensive analysis of thermal comfort under the Internet of Things framework highlights the contribution of data to improving thermal comfort and energy efficiency (30). IoT technologies can create safer and more comfortable working environments by reducing thermal stress, which can increase worker productivity and lower the chance of heat-related accidents. Improved overall productivity results from quick

interventions and ongoing monitoring to ensure that employees can execute their jobs without jeopardizing their health (31). IoT systems provide precise and timely data on environmental conditions and workers' health, which assists enterprises in adhering to occupational health and safety laws. Ensuring a healthy working environment and preventing heat-related illnesses depend heavily on compliance. One way in which these technologies assist with regulatory compliance is the application of IoT in measuring thermal comfort in industrial settings (32).

4. Challenges and Limitations

Although the Internet of Things (IoT) has great promise to lessen thermal stress brought on the weather, there are a number of barriers and difficulties in the way of its successful application:

a. Data Accuracy and Reliability

Ensuring the accuracy and dependability of data gathered by IoT devices is one of the main obstacles. To be useful, wearable technology and environmental sensors used to detect thermal stress must offer accurate measurements. Inaccurate data can result in worker hazard scenarios and inaccurate evaluations of thermal stress levels. A study on transformational IoT sensing for thermal exposures pointed out that one major obstacle continues to be sensor accuracy in changing environmental circumstances (31).

b. Privacy and Security Concerns

The gathering and sharing of private health information via Internet of Things devices gives rise to serious privacy and security issues. It is essential to safeguard private data on employees' physiological status against intrusions or illegal access. This problem is especially important for IoT-based Federated Learning systems, since heat stress can compromise both individual privacy and the overall global model (33).

c.Integration and Interoperability

It can be difficult to integrate disparate IoT systems and devices from different manufacturers. Developing a comprehensive thermal stress management system requires ensuring interoperability between various sensors, DPUs, and alarm systems. This integration may be hampered by the IoT technologies' lack of standardization (34).

d. Power Management and Battery Life

Many Internet of Things (IoT) devices, particularly wearable ones, that monitor temperature stress are battery-operated. A major difficulty is ensuring lengthy battery life while maintaining continuous monitoring, especially in harsh or distant situations where frequent recharge might not be possible (35).

e.Environmental Durability

Extreme temperatures, high humidity, and dust are just a few of the climatic extremes that Internet of Things devices deployed outdoors must endure. It is a technical challenge to design devices that can operate consistently under these conditions and deliver reliable data (31).

f. Data Processing and Real-time Analysis

It is computationally demanding to process massive amounts of data from several IoT devices in real-time and deliver meaningful insights on thermal stress. According to a study on real-time thermal stress prediction systems, creating effective algorithms for real-time thermal stress prediction is still a work in progress (35).

g.User Acceptance and Adoption

It can be difficult to get employees to regularly assess thermal stress using wearable IoT devices. Users may become resistant because to worries about privacy, comfort, and how invasive continuous monitoring is regarded (36).

h. Cost and Scalability

Large-scale IoT solution implementation for managing thermal stress can be expensive, particularly for small and medium-sized businesses. One of the biggest obstacles to adoption may be the initial cost of the necessary hardware, software, and training (34).

I. Regulatory Compliance

It can be difficult to make sure that Internet of Things-based thermal stress management solutions abide by local occupational health and safety laws. This is a challenge that is especially pertinent to multinational corporations that operate in many regulatory regimes (35).

j. Environmental Impact

IoT device development, use, and disposal may have an impact on the environment and may even exacerbate the climate change problems that the devices are intended to combat. It is crucial to weigh the advantages of IoT in managing thermal stress against its effects on the environment (34).

Conclusion:

There is significant potential for reducing thermal stress brought on by weather conditions through the incorporation of Internet of Things (IoT) technologies into occupational health practices. The utilization of these technologies facilitates data-driven decision-making, predictive analytics, and real-time monitoring, all of which increase worker productivity and safety. IoT solution installation is not without its difficulties, though. To fully reap the benefits of IoT in this setting, issues such data accuracy, privacy and security concerns, integration and interoperability challenges, power management, environmental durability, and user acceptance must be addressed. Further challenges that call for careful design and management include the cost and scalability of IoT systems, as well as the requirement for regulatory compliance and consideration of environmental implications. It will take continued research, technical innovation, and cooperative efforts from all stakeholders—technologists, occupational health specialists, regulatory agencies, and end users—to overcome these obstacles. IoT technologies can be efficiently used to build safer, more resilient workplaces in the face of climate change by addressing these issues. Reducing heat stress and protecting workers' health and well-being in increasingly extreme climate circumstances will need the proactive adoption of IoT solutions together with a dedication to continual development and adaptation.

Ethical approval

Not applicable.

Informed consent

Not applicable.

Conflict of interest

The authors declare no conflict of interest.

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